Effects of silvicultural treatments on mechanical properties of *Pinus sylvestris* var. *mongolica* plantations

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Abstract: A study was conducted to determine the influences of initial planting densities, thinning intensities, exposures and slope sites on physical property (wood density) and mechanical properties such as modulus of elasticity (MOE), bending strength, impact strength, compression strength along grain and hardness) of *Pinus sylvestris* var. *mongolica* plantation in Mao'ershan Forest Farm, Northeast China. Results show that the different initial planting densities (1.5 m×1.0 m, 1.5 m×2.0 m and 1.5 m×2.5 m) had significant effects on wood density and MOE, and the highest mean wood density and indexes of mechanical properties occurred in the stand with an initial planting density of 1.5 m×1.0 m. The indexes of mechanical properties such as hardness of end, bending strength, MOE and compression strength along grain of wood increased after mild thinning, but decreased after violent thinning. The exposures (sunny slope and shady slope) had a significant effect on MOE, and the highest mean MOE occurred on sunny slope. The slope sites (upper site and lower site) had a significant effect on wood density and main mechanical properties, except hardness. The highest mean wood density and mechanical properties occurred at lower site.

Keywords: Silvicultural treatments; Plantation; *Pinus sylvestris* var. *mongolica*; Mechanical properties

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Introduction

Physical and mechanical properties of wood are the most important characteristics in scientific conversion and reasonable utilization of wood. Different tree species have bigger difference in their physical and mechanical properties, and even for the same tree species, this difference is very significant between or within trunk. The reasons are mainly due to the fact that the different growth conditions led to the differences of physical and mechanical properties of wood (Li 1993; Guo 2001).

Pinus sylvestris var. *mongolica* Litv is one variation of Scots pine (*Pinus sylvestris* L.), which is mainly distributed in Far East, with a tree height of 30-40 m and a diameter at breast height of 80-90 cm in adult phase. Moreover, *P. sylvestris* var. *mongolica* has many good performances such as strong adaptability, cold resistance (about –50℃), good wood quality and fast growth. Thus it was widely used in silviculture, construction, board of chest, wood fiber products, pulp chips, and shipping etc. Many indexes have been used to describe the physical and mechanical properties of wood. In this study, we chose the factors such as wood density, bending strength, modulus of elasticity (MOE), impact strength, and hardness, etc., which affect the use of *P. sylvestris* var. *mongolica* plantations greatly, to study the wood properties.

Materials and methods

The study site is located in Maoershan Forest Farm, Northeast Forestry University, in the northeast of China (45°20'N, 127°30'E). Trees in age of 18–28 were sampled from silvicultural and control stands.. Different experimental plots in each stand were established. In each plot, three trees were sampled from different initial planting densities (1.5 m×1.0 m, 1.5 m×2.0 m and 1.5 m×2.5 m), different thinning intensities (no thinning, mild thinning and violent thinning), different slope sites (upper site and lower site), and different exposures (sunny slope and shady slope). Sampling process was carried out following the National Criterion GB1927-91. A small block of 1.2 m in length was cut from each tree, and taken back laboratory for testing physical and mechanical properties of wood. The outline of samples is shown in Table 1. The processing and testing of samples were carried out following the National Criterion GB1927-1973-91.

Results and discussion

Effect of initial planting density on wood density

It is documented that variance of wood density is the primary theory basis for improving wood quality (Liu 1997; Sheng 1992). The wood density of *P. sylvestris* var. *mongolica* increased with the increase of initial planting density (Table 2), and the result of variance analysis (Table 3) also shows that the difference in wood density is statistically significant between the woods with different initial planting densities. This indicates that wood density is affected by initial density. In order to obtain the wood with an especial density, it is necessary to choose reasonable initial density.

Effect of initial planting density on mechanical properties

The wood sample from stand with an initial planting density of 1.5 m×1.0 m had highest values in mechanical properties such as the hardness of end, bending strength, MOE, compression strength along grain, and the impact strength, while that from the stand with an initial density of 1.5 m×2.5 m had lowest values in those mechanical properties (Table 2). This indicates that me-

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chanical properties of wood are improved along with the decrease of initial planting density of *P. sylvestris* var. *mongolica* plantations. The result of variance analysis (Table 3) shows that the difference in MOE is statistically significant between the woods with different initial planting densities, but other indexes of mechanical properties are not statistically significant.

Table 1. Outline of samples

Treatments		Number /n	Age /a	DBH (cm)	Slope sites	Exposures	Initial planting density
Initial densities	1.5 m×1.0m	3	26	13.13	Lower	Sunny	1.5 m×1.0 m
	1.5 m×2.0 m	3	23	12.01	Lower	Sunny	1.5m×2.0m
	1.5 m×2.5 m	3	26	13.76	Lower	Sunny	1.5m×2.5m
Thinning weights	absent	3	26	13.13	Lower	Sunny	1.5m×1.0m
	Mild	3	29	13.42	Lower	Sunny	2m×3m
	Violent	3	31	15.12	Lower	Sunny	4m×3m
Exposures	Sunny	3	35	15.42	Middle	Sunny	2m×3m
	Shady	3	29	13.95	Middle	Shady	2m×3m
Slope sites	Lower	3	30	13.25	Lower	Sunny	2m×2.5m
	Upper	3	31	14.12	Upper	Sunny	2m×2.5m

Table 2. Testing results of wood mechanical properties with different planting densities or thinning intensities

Mechanical properties	Initial planting densities			Thinning intensities		
	1.5 m×1.0 m	1.5 m×2.0 m	1.5 m ×2.5 m	absent thinning	Mild thinning	Violent thinning
Wood density (g·cm^{-3})	0.378	0.374	0.365	0.378	0.375	0.361
Standard deviation	0.038	0.049	0.037	0.039	0.041	0.040
Coefficient of variation (%)	10.02	13.3	10.16	10.02	11.29	11.081
Modulus of elasticity (MPa)	92.013	88.804	86.281	90.013	92.939	89.078
Standard deviation	7.673	7.537	6.344	7.673	6.974	8.885
Coefficient of variation (%)	8.34	8.48	7.35	8.54	7.475	9.97
Bending strength (GPa)	14.422	12.832	10.865	14.422	15.809	13.386
Standard deviation	5.83	5.58	5.21	5.83	6.97	5.995
Coefficient of variation (%)	40.42	43.48	47.95	40.42	50.47	38.96
Impact strength（kJ·cm^{-2}）	24.923	24.371	23.107	24.923	24.743	24.082
Standard deviation	3.026	4.581	7.9341	3.026	4.37	4.117
Coefficient of variation (%)	12.14	18.8	34.34	12.14	17.66	17.09
Compression strength along grain (MPa)	40.923	41.922	39.628	40.923	42.287	41.287
Standard deviation	5.741	4.018	5.407	5.741	5.388	5.487
Coefficient of variation (%)	14.06	9.57	13.64	14.06	12.74	13.28
Hardness of end (kg·cm^{-2})	258.412	254.281	251.744	258.411	259.32	254.453
Standard deviation	33.451	41.5	34.87	33.451	40.177	36.519
Coefficient of variation (%)	12.94	16.32	13.85	12.94	15.49	14.35

Table 3. Variance analysis of wood mechanical properties with different initial planning densities or thinning intensities

Physical and mechanical properties	Initial densities		Thinning intensities	
	F	Fn (0.05)	F	Fn (0.05)
Wood density	3.628*	3.124	0.999	3.107
Modulus of elasticity	4.590*	3.104	3.679*	3.101
Bending strength	2.883	3.108	1.976	3.104
Impact strength	0.858	3.101	3.649*	3.101
Compression strength along grain	1.52	3.101	3.893*	3.101
Hardness	2.107	3.127	0.446	3.107

Effects of thinning intensities on wood density

The effect of thinning on wood density has been widely studied, but the results were controversial. Markstrom (1983) found that the effect of thinning on wood density was not significant, but Cown (1981) and Zhou (1980) reported that wood density decreased because of thinning, and Wu (1995) reported that wood density increased for reasonable thinning.

Our study showed that the wood density of *P. sylvestris* var. *mongolica* from absent thinning stand is the highest, followed by that from the mild thinning stand, and that from violent thinning stand is lowest (Table 2). However, the result of variance analysis shows that the wood density is not significant difference between the stands with different thinning intensities (Table 3). This result agrees with Markstrom's viewpoints that wood density is not affected by thinning.

Effects of thinning intensities on mechanical properties

The hardness of end, bending strength, MOE and compression strength along grain of the wood samples from the mild thinning stand are higher than those of wood samples from absent thinning stand. Most of indexes of mechanical properties of wood under violent thinning are lower than those under mild thinning or absent thinning (Table 2). The result of variance analysis shows that the differences in MOE, compression strength along grain, and impact strength are statistically significant among the stands with different thinning intensities (Table 3).

Effects of exposures on wood density

The wood density of trees planted on sunny slope is lower than that of those planted on shady slope (Table 4). The reason is that the tracheid diameter and the width of growth rings of trees planted on sunny slope are larger than those planted on shady slope (Panshin 1980). The result of variance analysis shows that the difference of wood density is not significant between sunny slope and shady slope (Table 5).

Effects of exposures on mechanical properties

The hardness of end, bending strength, MOE, and compression strength along grain of wood on sunny slope are higher than those on shady slope, but the impact strength appears contrarily (Table 4). The result of variance analysis shows that the difference of MOE is significant between sunny slope and shady slope (Table 5).

Table 4. Testing results of wood mechanical properties on different exposures and slope sites

Mechanical properties	Exposures		Slope sites	
	Sunny	Shady	Upper	Lower
Wood density ($g\cdot cm^{-3}$)	0.366	0.380	0.345	0.380
Standard deviation	0.046	0.056	0.042	0.044
Coefficient of variation (%)	12.47	14.6	12.20	11.64
Modulus of elasticity (MPa)	90.484	84.96	85.583	89.229
Standard deviation	10.45	10.619	12.856	9.033
Coefficient of variation (%)	11.54	12.49	15.00	10.12
Bending strength (GPa)	14.141	11.776	12.936	14.653
Standard deviation	7.213	6.39	6.529	5.721
Coefficient of variation (%)	51.01	54.26	50.50	39.04
Impact strength（$kJ\cdot cm^{-2}$）	23.45	23.915	21.424	23.525
Standard deviation	5.415	4.195	3.41	7.38
Coefficient of variation (%)	23.09	17.54	15.90	31.37
Compression strength along grain (MPa)	40.833	39.917	38.978	40.87
Standard deviation	3.614	5	4.88	3.67
Coefficient of variation (%)	8.85	12.52	12.5	8.97
Hardness of end ($kg\cdot cm^{-2}$)	257.12	254.841	252.471	255.241
Standard deviation	37.11	37.9	41.263	38.69
Coefficient of variation (%)	14.43	14.87	16.34	15.196

Effects of slope sites on wood density

The wood density of trees planted at upper site is slightly lower than those planted at lower site (Table 4). And the result of variance analysis shows that the difference of wood density is statistically significant between upper and lower sites (Table 5).

Table 5. Variance analysis of wood mechanical properties on different exposures and slope sites

Physical and mechanical properties	Exposures		Slope sites	
	F	Fn (0.05)	F	Fn (0.05)
Wood density	0.561	3.996	4.764*	4.001
Modulus of elasticity	4.055*	4.01	4.61*	4.007
Bending strength	1.773	4.01	5.173*	4.007
Impact strength	1.386	4.006	4.47*	4.007
Compression strength along grain	0.661	4.006	6.955**	4.007
Hardness	0.058	3.995	0.073	4.004

Effects of slope sites on mechanical properties

From Table 4, we can see that mechanical properties of wood at lower site are higher than those at upper site. The result of variance analysis shows that the differences of mechanical properties are statistically significant between upper site and lower site (Table 5). Therefore, lower site could be chosen to establish the plantation of *P. sylvestris* var. *mongolica* for construction and plywood uses.

Conclusions

The wood density and mechanical properties of *P. sylvestris* increased along with the increase of initial planting density of plantations. Of the indexes of mechanical properties, only MOE or wood density is statistically significant difference between the woods from different initial planting densities. Thus, it is clear that wood density and MOE are affected by initial planting density.

From the analysis of thinning intensity on wood density and mechanical properties, a conclusion can be made that mild thinning could improve MOE, bending strength, hardness of end and accelerate tree growth. Violent thinning may decrease wood density, MOE, bending strength, impact strength, and hardness of end. When establishing the plan of silviculture, mild thinning should be considered to accelerate tree growth and improve the wood quality

The wood density of *P. sylvestris* var. *mongolica* trees planted on sunny slope is lower than that of those planted on shady slope, and except the impact strength, all the indexes of mechanical properties of wood of trees on sunny slope are higher than those on shady slope.. There is a significant difference in MOE for the trees on sunny slope and shady slope.

The wood densities or mechanical properties of trees planted at upper site are slightly lower than those planted at lower site. And the difference of wood density or mechanical properties is statistically significant between upper site and lower site. Lower site can be chosen to establish the plantation of *P. sylvestris* var. *mongolica* for construction and plywood.

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